

## Claims

WHAT IS CLAIMED IS:

1. A method comprising:

computing a first probe estimate from a first probe sequence transmitted over a network from a first device to a second device;

computing a second probe estimate from a second probe sequence transmitted over the network from the first device to the second device, the first probe sequence providing a different load to the network than the second probe sequence; and

estimating a sustainable capacity of the network based on the first probe estimate and the second probe estimate.

2. The method of claim 1 wherein the sustainable capacity is further based on a minimum delay time of individual round-trip delay times associated with the first probe sequence and the second probe sequence.

3. The method of claim 1 wherein the sustainable capacity of the network relates to data traffic flowing from the first device to the second device, and further comprising:

computing a third probe estimate from a third probe sequence transmitted over the network from the second device to the first device;

computing a fourth probe estimate from a fourth probe sequence transmitted over the network from the second device to the first device, the third probe sequence providing a different load to the network than the fourth probe sequence; and

1       estimating a reverse sustainable capacity of the network for data traffic  
2       from the second device and the first device based on the third probe estimate and  
3       the fourth probe estimate.

4       4. The method of claim 1 wherein the first probe sequence includes probe  
5       packets periodically transmitted from the first device to the second device.

6       5. The method of claim 1 wherein the estimating operation comprises  
7       computing an algorithm substantially of the form:

$$SusCap_{est} = \delta m \frac{\hat{D}_2 - D_{min}}{\hat{D}_2 - \hat{D}_1}$$

9       wherein  $SusCap_{est}$  represents the sustainable capacity value,  $\delta m$  represents a  
10       load difference between the second probe sequence and the first probe sequence,  
11        $\hat{D}_2$  represents the second probe estimate,  $\hat{D}_1$  represents the first probe estimate,  
12       and  $D_{min}$  represents a minimum delay time of individual round-trip delay times  
13       associated with the first load probe sequence and the second load probe sequence.

14       6. The method of claim 1 wherein the estimating operation comprises  
15       computing an algorithm substantially of the form:

$$SusCap_{est} = \delta m \frac{\hat{D}_2}{\hat{D}_2 - \hat{D}_1}$$

16       wherein  $SusCap_{est}$  represents the sustainable capacity value,  $\delta m$  represents a  
17       load difference between the second probe sequence and the first probe sequence,  
18        $\hat{D}_2$  represents the second probe estimate, and  $\hat{D}_1$  represents the first probe  
19       estimate.

1        7. The method of claim 1 wherein neither the first probe sequence nor the  
2 second probe sequence saturate the network.

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4        8. The method of claim 1 wherein the second probe sequence loads the  
5 network more than the first probe sequence.

6        9. The method of claim 1 further comprising:  
7        generating a first probe sequence, wherein each probe packet in the first  
8 probe sequence has a unique signature.

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10       10. The method of claim 1 further comprising:  
11       timestamping each packet in the first probe sequence prior to transmission  
12 to the second network device.

13       11. The method of claim 1 further comprising:  
14       timestamping each response to each probe packet in the first probe  
15 sequence after to reception of the probe packet from the second network device.

16       12. The method of claim 1 wherein each probe estimate is an average  
17 round-trip delay time.

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19       13. The method of claim 1 wherein each probe estimate is a median round-  
20 trip delay time.

21       14. The method of claim 1 wherein each probe estimate is a range of round-  
22 trip delay times.

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24       15. The method of claim 1 wherein each probe estimate is a standard  
25 deviation of round-trip delay times.

1 16. A computer program product encoding a computer program for  
2 executing on a computer system a computer process, the computer process  
3 comprising:

4 computing a first probe estimate from a first probe sequence transmitted  
5 over a network from a first device to a second device;

6 computing a second probe estimate from a second probe sequence  
7 transmitted over the network from the first device to the second device, the first  
8 probe sequence providing a different load to the network than the second probe  
9 sequence; and

10 estimating a sustainable capacity of the network based on the first probe  
11 estimate and the second probe estimate.

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13 17. The computer program product of claim 16 wherein the sustainable  
14 capacity value is further based on a minimum delay time of individual round-trip  
15 delay times associated with the first probe sequence and the second probe  
16 sequence.

17 18. The computer program product of claim 16 wherein the sustainable  
18 capacity of the network relates to data traffic flowing from the first device to the  
19 second device, and further comprising:

20 computing a third probe estimate from a third probe sequence transmitted  
21 over the network from the second device to the first device;

22 computing a fourth probe estimate from a fourth probe sequence  
23 transmitted over the network from the second device to the first device, the third  
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1 probe sequence providing a different load to the network than the fourth probe  
2 sequence; and

3 estimating a reverse sustainable capacity value in the network  
4 characterizing sustainable capacity of the network for data traffic from the second  
5 device and the first device based on the third probe estimate and the fourth probe  
6 estimate.

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8 19. The computer program product of claim 16 wherein the first probe  
9 sequence includes probe packets periodically transmitted from the first device to  
10 the second device.

11 20. The computer program product of claim 16 wherein the estimating  
12 operation comprises computing an algorithm substantially of the form:

$$13 \quad SusCap_{est} = \delta m \frac{\hat{D}_2 - D_{\min}}{\hat{D}_2 - \hat{D}_1}$$

15 wherein  $SusCap_{est}$  represents the sustainable capacity value,  $\delta m$  represents a  
16 load difference between the second probe sequence and the first probe sequence,  
17  $\hat{D}_2$  represents the second probe estimate,  $\hat{D}_1$  represents the first probe estimate,  
18 and  $D_{\min}$  represents a minimum delay time of individual round-trip delay times  
19 associated with the first load probe sequence and the second load probe sequence.  
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21 21. The computer program product of claim 16 wherein the estimating  
22 operation comprises computing an algorithm substantially of the form:

$$23 \quad SusCap_{est} = \delta m \frac{\hat{D}_2}{\hat{D}_2 - \hat{D}_1}$$

1 wherein  $SusCap_{est}$  represents the sustainable capacity value,  $\delta m$  represents a  
2 load difference between the second probe sequence and the first probe sequence,  
3  $\hat{D}_2$  represents the second probe estimate, and  $\hat{D}_1$  represents the first probe  
4 estimate.

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6 22. The computer program product of claim 16 wherein neither the first  
7 probe sequence nor the second probe sequence saturate the network.

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9 23. The computer program product of claim 16 wherein the second probe  
10 sequence loads the network more than the first probe sequence.

11 24. The computer program product of claim 16 wherein the computer  
12 process further comprises:

13 generating a first probe sequence, wherein each probe packet in the first  
14 probe sequence has a unique signature.

15 25. The computer program product of claim 16 wherein the computer  
16 process further comprises:

17 timestamping each packet in the first probe sequence prior to transmission  
18 to the second network device.

19 26. The computer program product of claim 16 wherein the computer  
20 process further comprises:

21 timestamping each response to each probe packet in the first probe  
22 sequence after to reception of the probe packet from the second network device.  
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24 27. The computer program product of claim 16 wherein each probe estimate  
25 is an average round-trip delay time.

1           28. The computer program product of claim 16 wherein each probe estimate  
2 is a median round-trip delay time.

3           29. The computer program product of claim 16 wherein each probe estimate  
4 is a range of round-trip delay times.

5           30. The computer program product of claim 16 wherein each probe estimate  
6 is a standard deviation of round-trip delay times.  
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1 31. A system comprising:

2 a probe sequence generator that generates a first probe sequence and a  
3 second probe sequence;

4 a communication module that transmits the first probe sequence and the  
5 second probe sequence to a target, receives a first response sequence associated  
6 with the first probe sequence and a second response sequence associated with the  
7 second probe sequence; and computes a first probe estimate from the first probe  
8 sequence and a second probe estimate from the second probe sequence; and

9 a probe performance analyzer that estimates a sustainable capacity in the  
10 network characterizing sustainable capacity of the network for data traffic from  
11 the first device and the second device based on the first probe estimate and the  
12 second probe estimate.

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14 32. The system of claim 31 wherein the sustainable capacity is further based  
15 on a minimum delay time of individual round-trip delay times associated with the  
16 first probe sequence and the second probe sequence.

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18 33. The system of claim 31 wherein the first probe sequence includes probe  
19 packets periodically transmitted from the first device to the second device.

20 34. The system of claim 31 wherein the probe performance analyzer  
21 computes an algorithm substantially of the form:

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$$SusCap_{est} = \delta m \frac{\hat{D}_2 - D_{min}}{\hat{D}_2 - \hat{D}_1}$$
  
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1 wherein  $SusCap_{est}$  represents the sustainable capacity value,  $\delta m$  represents a  
2 load difference between the second probe sequence and the first probe sequence,  
3  $\hat{D}_2$  represents the second probe estimate,  $\hat{D}_1$  represents the first probe estimate,  
4 and  $D_{min}$  represents a minimum delay time of individual round-trip delay times  
5 associated with the first load probe sequence and the second load probe sequence.

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7 35. The system of claim 31 wherein the probe performance analyzer  
8 computes an algorithm substantially of the form:

$$9 \quad SusCap_{est} = \delta m \frac{\hat{D}_2}{\hat{D}_2 - \hat{D}_1}$$

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11 wherein  $SusCap_{est}$  represents the sustainable capacity value,  $\delta m$  represents a  
12 load difference between the second probe sequence and the first probe sequence,  
13  $\hat{D}_2$  represents the second probe estimate, and  $\hat{D}_1$  represents the first probe  
14 estimate.

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16 36. The system of claim 31 wherein neither the first probe sequence nor the  
17 second probe sequence saturate the network.

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19 37. The system of claim 31 wherein each probe estimate is an average  
20 round-trip delay time.

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22 38. The system of claim 31 wherein each probe estimate is a median round-  
23 trip delay time.

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25 39. The system of claim 31 wherein each probe estimate is a range of  
round-trip delay times.

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40. The system of claim 31 wherein each probe estimate is a standard deviation of round-trip delay times.

1 41. A method comprising:  
2 computing a first round-trip delay trend associated with a first probe  
3 sequence transmitted over a network from a first device to a second device;  
4 computing a second round-trip delay trend associated with a second probe  
5 sequence transmitted over the network from the first device to the second device;  
6 estimating a maximum capacity and a background load of the network  
7 based on the first round-trip delay trend and the second round-trip delay trend; and  
8 estimating a sustainable capacity of the network based on the maximum  
9 capacity and the background load of the network.  
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11 42. The method of claim 41 wherein a number of probe packets in the first  
12 load probe sequence equals a number of probe packets in the second load probe  
13 sequence.  
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15 43. The method of claim 41 wherein a size of all probe packets in the first  
16 load probe sequence equals a size of all probe packets in the second load probe  
17 sequence and an inter-probe gap between probe packets in the first load probe  
18 sequence does not equal an inter-probe gap between probe packets in the second  
19 load probe sequence.  
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21 44. The method of claim 41 wherein an inter-probe gap between probe  
22 packets in the first load probe sequence equals an inter-probe gap between probe  
23 packets in the second load probe sequence and a size of all probe packets in the  
24 first load probe sequence does not equal a size of all probe packets in the second  
25 load probe sequence

1           45. The method of claim 41 wherein the operation of computing the first  
2 round-trip delay trend comprises:  
3           computing the average round-trip delay difference associated with the first  
4 probe sequence.  
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1 46. A computer program product encoding a computer program for  
2 executing on a computer system a computer process, the computer process  
3 comprising:

4 computing a first round-trip delay trend associated with a first probe  
5 sequence transmitted over a network from a first device to a second device;

6 computing a second round-trip delay trend associated with a second probe  
7 sequence transmitted over the network from the first device to the second device;

8 estimating a maximum capacity and a background load of the network  
9 based on the first round-trip delay trend and the second round-trip delay trend; and

10 estimating a sustainable capacity of the network based on the maximum  
11 capacity and the background load of the network.  
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13 47. The computer program product of claim 46 wherein a number of probe  
14 packets in the first load probe sequence equals a number of probe packets in the  
15 second load probe sequence.

16 48. The computer program product of claim 46 wherein a size of all probe  
17 packets in the first load probe sequence equals a size of all probe packets in the  
18 second load probe sequence and an inter-probe gap between probe packets in the  
19 first load probe sequence does not equal an inter-probe gap between probe packets  
20 in the second load probe sequence.  
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22 49. The computer program product of claim 46 wherein an inter-probe gap  
23 between probe packets in the first load probe sequence equals an inter-probe gap  
24 between probe packets in the second load probe sequence and a size of all probe  
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1 packets in the first load probe sequence does not equal a size of all probe packets  
2 in the second load probe sequence

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4 50. The computer program product of claim 46 wherein the operation of  
5 computing the first round-trip delay trend comprises:

6 computing the average round-trip delay difference associated with the first  
7 probe sequence.  
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1 51. A system comprising:

2 a probe sequence generator that generates a first probe sequence and a  
3 second probe sequence;

4 a communication module that transmits the first probe sequence and the  
5 second probe sequence to a target, receives a first response sequence associated  
6 with the first probe sequence and a second response sequence associated with the  
7 second probe sequence; and computes first round-trip delay times of the first probe  
8 sequence and second round-trip delay times of the second probe sequence;

9 a probe performance analyzer that computes a first round-trip delay trend  
10 associated with a first probe sequence and a second round-trip delay trend  
11 associated with a second probe sequence, estimates a maximum capacity and a  
12 background load of the network based on the first round-trip delay trend and the  
13 second round-trip delay trend, and estimates a sustainable capacity of the network  
14 based on the maximum capacity and the background load of the network.  
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16 52. The system of claim 51 wherein a number of probe packets in the first  
17 load probe sequence equals a number of probe packets in the second load probe  
18 sequence.

19 53. The system of claim 51 wherein a size of all probe packets in the first  
20 load probe sequence equals a size of all probe packets in the second load probe  
21 sequence and an inter-probe gap between probe packets in the first load probe  
22 sequence does not equal an inter-probe gap between probe packets in the second  
23 load probe sequence.  
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1           54. The system of claim 51 wherein an inter-probe gap between probe  
2 packets in the first load probe sequence equals an inter-probe gap between probe  
3 packets in the second load probe sequence and a size of all probe packets in the  
4 first load probe sequence does not equal a size of all probe packets in the second  
5 load probe sequence

6           55. The system of claim 51 wherein the probe performance analyzer further  
7 computes the average round-trip delay difference associated with the first probe  
8 sequence.  
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56. A method comprising:

determining a network saturation window by incrementally increasing the load of probe packet sequence between a client and a server on a network until at least one probe packet is lost;

detecting a time period associated with the network saturation window; and

estimating a sustainable capacity of the network between the client and the server from a ratio of the network saturation window to the time period.

57. The method of claim 56 wherein detecting the time period comprises:

detecting a minimum round-trip delay time on the network between the client and the server, wherein the minimum round-trip delay time constitutes the time period.

58. The method of claim 56 wherein detecting the time period comprises sustaining traffic within the network saturation window on the network between the client and the server for a predetermined period of time and estimating the sustainable capacity of the network comprises computing the number of bytes per unit time transmitted in the network saturation window during the time period.

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2 59. A computer program product encoding a computer program for  
3 executing on a computer system a computer process, the computer process  
4 comprising:

5 determining a network saturation window by incrementally increasing the  
6 load of probe packet sequence between a client and a server on a network until at  
7 least one probe packet is lost;

8 detecting a time period associated with the network saturation window; and  
9 estimating a sustainable capacity of the network between the client and the  
10 server from a ratio of the network saturation window to the time period.

11 60. The computer program product of claim 59 wherein detecting the time  
12 period comprises:

13 detecting a minimum round-trip delay time on the network between the  
14 client and the server, wherein the minimum round-trip delay time constitutes the  
15 time period.

16 61. The computer program product of claim 59 wherein detecting the time  
17 period comprises sustaining traffic within the network saturation window on the  
18 network between the client and the server for a predetermined period of time and  
19 estimating the sustainable capacity of the network comprises computing the  
20 number of bytes per unit time transmitted in the network saturation window during  
21 the time period.  
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1           62. A system comprising:

2           a communications module that transmits a probe packet sequence of  
3 incrementally increasing load between a client and a server on a network; and

4           a sustainable capacity probe module that determines a network saturation  
5 window from the probe packet sequence based on when at least one probe packet  
6 is lost and estimates a sustainable capacity of the network between the client and  
7 the server from a ratio of the network saturation window to a determined time  
8 period.

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10           63. The system of claim 62 wherein the determined time period is a  
11 minimum round-trip delay time detected between the receiver that the sender.

12           64. The system of claim 62 wherein the determined time period is a period  
13 of transmitting sustained traffic within the network saturation window on the  
14 network between the client and the server.  
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